Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina

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REGIONAL AQUIFER-SYSTEM ANALYSIS

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Depositional environments

Rocks of Paleocene age were for the most part deposited in marine or marginal marine environments. In updip areas, the basal sands of the Clayton Formation represent a transgressive marine sand. Their western equivalents, the laminated, fossiliferous silt and sand of the Pine Barren Member of the Clayton, represent a shallow, restricted marine environment such as a bay or an estuary. Both the Pine Barren and the basal Clayton sands were succeeded by soft, micritic (McBryde Limestone Member) to shelly, sandy limestone that represents a shallow, open marine environment. A minor regression of the sea followed deposition of this limestone, during which a shallow marine sand (part of the Clayton) was laid down in eastern Alabama and the blocky, massive, nonmarine to very shallow marine Porters Creek Formation was deposited in western Alabama. The Matthews Landing Marl Member of the Porters Creek was deposited in a restricted marine environment during a minor transgression near the end of Porters Creek time. In middip areas, the Clayton Formation and its equivalents are entirely shallow marine. The laminated silty sands of the Tuscahoma Formation were deposited in a restricted marine environment, probably a tidal flat. Periodically, local transgressions of the sea covered the tidal flat and allowed deposition of the Greggs Landing and Bells Landing Marl Members. Farther downdip, the massive marine clay that is the deeper water equivalent of the Clayton, the Nanafalia, and the Tuscahoma was deposited in quiet open-marine water in a midshelf area.

To the south and east of the clastic Paleocene rocks, the Cedar Keys Formation was deposited in a shallow, warm-water, carbonate bank environment. The extensive evaporite deposits of the Cedar Keys represent tidal flat or sabkha-type conditions that existed over wide areas and for a long time on this carbonate bank.

The basal part of the Naheola Formation in western Alabama (Oak Hill Member) represents a fluvial to very shallow marine (tidal flat accompanied by occasional oyster banks) environment. The succeeding Coal Bluff Marl Member of the Naheola was deposited in a restricted marine to very shallow open marine environment. Downdip, the Naheola probably passes by facies change into part of the massive, open marine clay that forms most of the downdip Paleocene. Well control is not available to show such a transition, however.

The Salt Mountain Limestone was deposited in an open marine, quiet, shallow-water environment. The Salt Mountain is thin and discontinuous, possibly as the result of postdepositional erosion. In wells where the Salt Mountain is absent and the Paleocene sequence consists entirely of marine clay, however, no disconformity is known to exist within the massive clay sequence.

The Gravel Creek Member of the updip Nanafalia Formation in western Alabama is a fluvial sand. It is overlain by the *"Ostrea thirsae"* beds and the Grampian Hills Member, both of which were deposited in a restricted marine environment. The Baker Hill Formation, which is the equivalent of the upper Nanafalia in eastern Alabama and western Georgia, was deposited in fluvial and estuarine environments. Downdip, the Nanafalia Formation grades into and becomes part of the massive, marine, undifferentiated Paleocene clay.

The Ellenton Formation is thought to represent a basal shallow marine transgressive deposit that consists in large part of reworked sediments from the underlying Cretaceous. The Beaufort(?) Formation of Gohn and others (1977) consists mostly of marginal marine beds. The overlying Black Mingo Formation is shallow marine for the most part and reflects a slight regression followed by a transgression.

EOCENE SERIES

General

The thick sequence of Eocene rocks that is everywhere present in the study area can be readily divided into rocks of early, middle, and late Eocene age. The rocks mapped during this study as middle Eocene and late Eocene correspond to the Claibornian and Jacksonian provincial Gulf Coast stages, respectively. Rocks of early Eocene age as mapped correspond to the upper part of the Sabinian provincial stage. These relationships are shown on the generalized correlation chart (pl. 2). As the section of this report dealing with the Paleocene Series discusses, the traditionally accepted concept that the Sabinian Stage is equivalent to the Wilcox Group and that both terms refer to rocks of early Eocene age is no longer valid. Many of the units formerly assigned to the lower part of the Sabinian Stage are now known to be of Paleocene age, rather than Eocene (Oliver and Mancini, 1980; Gibson, 1980, 1982a). These units are accordingly included in the Paleocene Series as mapped in this report.

Eocene strata in the study area are extensive, thick, and, where they consist of carbonate rocks, generally highly permeable. The major part of the Floridan aquifer system is made up of Eocene rocks, which commonly show highly developed primary (intergranular) and secondary (dissolution) porosity, particularly in their upper parts. Like the Paleocene rocks, carbonate rocks of both early and middle Eocene age grade updip by facies change into calcareous, glauconitic, clastic rocks. This carbonate-clastic transition lies farther to the north and west in lower Eocene strata than it does in the underlying Paleocene and is located still farther north and west in middle Eocene rocks. Upper Eocene rocks retain their carbonate character in many places up to the point where they are truncated by erosion. The overall effect is that of a general regional transgression that began in Paleocene time and persisted through the late Eocene and during which the marine facies of progressively younger rocks extended progressively farther and farther inland. Several minor regressions punctuated this general transgression. These observations are consistent with the sea level curve of Vail and others (1977), which shows that sea level worldwide became progressively higher from early to late Eocene time.

Rocks of early Eocene age

Downdip, a lower Eocene carbonate sequence underlies southeastern Georgia and the Florida peninsula; updip, the remainder of the study area is underlain by clastic lower Eocene rocks. Locally, in South Carolina, the Eocene in the subsurface is an impure limestone. Plate 4 shows the configuration of the top of rocks of early Eocene age and the area where they crop out. Comparison of plate 4 with a map of the structural surface of the Paleocene (pl. 3) shows that, in Alabama and southwestern Georgia, lower Eocene rocks lie to the south and east of Paleocene rocks in offlap relationship. In central Georgia, however, beds of early Eocene age overlap and extend farther to the north than the underlying Paleocene rocks. Lower Eocene rocks are known to extend farther to the north in this overlap area than plate 4 shows, but they have been mapped during this study only to the limits of the well control used to delineate the Floridan aquifer system. In the western part of the study area, the configuration of the top of the early Eocene is contoured up to the limit of outcrop of these rocks (pl. 4).

Many of the large- to intermediate-scale structural features that affect the shape of the Paleocene surface (pl. 3) are recognizable on the early Eocene surface (pl. 4). Those features common to both maps include (1) the Peninsular arch in north-central Florida, (2) the Southeast Georgia embayment, and (3) a steep, steady slope toward the Gulf Coast geosyncline in the western part of the study area. The Southwest Georgia embayment in eastern panhandle Florida is a negative area on both the Paleocene and early Eocene tops, but this feature is deeper and narrower and extends farther to the northeast on the early Eocene surface than it does on the top of the Paleocene. The configuration of the South Florida basin in southwestern peninsular Florida likewise differs on the Paleocene and early Eocene surfaces. This feature was somewhat silled on its gulfward side in Paleocene time (pl. 3) but, at the end of early Eocene time (pl. 4) it was open to the gulf and appears to have been partially filled from the east and northeast. The Suwannee strait, a closed low that appears in southeastern Georgia on the map of the Paleocene surface, was apparently filled with sediments during early Eocene time and thus does not exist on the map of the early Eocene surface.

The maximum measured depth to the top of lower Eocene rocks is about 3,900 ft below sea level in well ALA-BAL-30 in the southern part of Baldwin County, Ala. The maximum contoured depth is below 4,200 ft, in the same general area. Lower Eocene rocks are slightly less than 800 ft below sea level on the crest of the Peninsular arch, from which they deepen in all directions. In the Southwest Georgia embayment and the South Florida basin, the top of lower Eocene rocks is below 2,600 ft.

The thickness of lower Eocene strata is shown on plate 5, along with the distribution of the clastic and carbonate facies within this unit. The clastic-carbonate boundary and much of the contouring shown on this plate are derived from well control. In areas of sparse control, the thickness of the early Eocene has been estimated as the difference between contoured altitudes of the top of the early Eocene (plate 4) and the top of the Paleocene (plate 3). In south Florida, lower Eocene rocks are more than 1,500 ft thick; in parts of panhandle Florida, they are more than 1,100 ft thick. On the crest of the Peninsular arch, these strata are less than 300 ft thick, and they thin to a featheredge in areas of outcrop.

Oldsmar Formation—Except for the Fishburne Formation that occurs locally in South Carolina, all the lower Eocene carbonate rocks in the study area are part of the unit that Applin and Applin (1944) named the Oldsmar Limestone. The Oldsmar, however, contains much dolomite, and thin beds of chert and evaporite deposits occur in the unit from place to place. The Oldsmar is therefore referred to as a "formation" rather than a "limestone."

The Oldsmar Formation consists mostly of off-white to light-gray micritic to finely pelletal limestone thickly to thinly interbedded with gray to tan to light-brown, fine to medium crystalline, commonly vuggy dolomite. The lower part of the formation is usually more extensively dolomitized than the upper part. Pore-filling gypsum and thin beds of anhydrite occur in the lowermost parts of the Oldsmar in places, particularly in a crescent-shaped band extending from Dixie County, Fla., northeast to southern Ware County, Ga

The location of this band, which locally comprises the base of the Floridan aquifer system, is shown on plate 33. In scattered places, the Oldsmar contains trace amounts of glauconite.

Applin and Applin (1944, p. 1699) defined the Oldsmar "to include the interval that is marked at the top by the presence of abundant specimens of *Helicostegina gyralis* Barker and Grimsdale...and that rests on the Cedar Keys limestone." This definition is unsatisfactory because (1) it is based on the microfaunal content of the strata, not on their lithologic characteristics, and (2) it is based on a species whose range is not restricted to the early Eocene. The author has found specimens of *H. gyralis* that show no evidence of reworking 50 to 70 ft above the top of the Oldsmar in rocks that are part of the overlying middle Eocene sequence ("Lake City" Limestone). Cole and Gravell (1952) reported this species from middle Eocene beds in Cuba. The Oldsmar Formation is thus redefined herein as the sequence of white to gray limestone and interbedded tan to light-brown dolomite that lies between the pelletal, predominantly brown limestone and brown dolomite of the middle Eocene and the gray, coarsely crystalline dolomite of the Cedar Keys Formation. *H. gyralis* is commonly found as part of a characteristic Oldsmar fauna that includes several other species of larger foraminifers listed in table 1. None of these species, however, is ubiquitous within the Oldsmar Formation, nor should they be the criterion by which the Oldsmar is defined.

The Oldsmar Formation underlies all of the Florida peninsula and the southeastern corner of Georgia (pl. 5). Westward, in the eastern part of the Florida panhandle, the Oldsmar becomes increasingly argillaceous and interfingers with calcareous clastic rocks. To the north, in south-central Georgia, the Oldsmar grades from limestone through argillaceous limestone and calcareous clay into glauconitic calcareous sand.

In addition to *H. gyralis*, the larger Foraminifera *Miscellanea nassauensis* Applin and Jordan, *Pseudophragmina (Proporocyclina) cedarkeysensis* Cole, and *Lockhartia sp.* are considered characteristic of the Oldsmar Formation.

UNDIFFERENTIATED LOWER EOCENE ROCKS—Lower Eocene rocks in the western part of the Florida panhandle consist of brownish- to greenish-gray, calcareous, slightly glauconitic shale and siltstone that are occasionally micaceous. Thin beds of fine-grained, slightly glauconitic sandstone and off-white sandy glauconitic limestone occur sporadically throughout the predominantly argillaceous section. These rocks are part of the unit that was called the "clastic facies of Wilcox age" by Applin and Applin (1944) and the "Wilcox Formation" by Chen (1965). Both Chen and the Applins included beds that are the downdip equivalents of the Nanafalia Formation, the Tuscahoma Formation, and the Salt Mountain Limestone in their "Wilcox" unit. In this report, the Nanafalia, Tuscahoma, and Salt Mountain are considered to be of Paleocene age and to grade downdip into undifferentiated argillaceous rocks of Paleocene age. The term "undifferentiated early Eocene rocks" is herein applied to the massive, predominantly argillaceous early Eocene section of western panhandle Florida. These strata grade eastward into the Oldsmar Formation and become less marine and slightly coarser grained updip in southern Alabama and southwestern Georgia, where they take on the character of the outcropping Hatchetigbee Formation.

Microfauna considered characteristic of undifferentiated rocks of early Eocene age include the Foraminifera *Globorotalia formosa gracilis* Bolli and *Rotalia trochoidiformis* (Lamarck). The Foraminifera *Globorotalia subbotinae* Morozova and *G. wilcoxensis* (Cushman and Ponton) are also considered characteristic of early Eocene rocks in the study area, even though these species are known to range downward into rocks of late Paleocene age elsewhere (Stainforth and others, 1975). The Ostracoda *Brackhcythere jessupensis* Howe and Garrett and *Haplocytheridea sabinensis* (Howe and Garrett) are also considered characteristic of these beds.

BASHI AND HATCHETIGBEE FORMATIONS—The lithology of the Hatchetigbee Formation in the area where it crops out in western Alabama is very similar to that of the underlying Tuscahoma. In practice, the two are difficult to separate except where the sandy, glauconitic, highly fossiliferous Bashi Formation (Gibson, 1982b) lies between them. The Bashi occurs only as erosional remnants in eastern Alabama and western Georgia. Downdip, the Hatchetigbee consists of interbedded fine sand and gray calcareous clay. The sand is lost in a short distance gulfward, and the argillaceous Hatchetigbee beds merge in middip areas with the underlying clay of the Tuscahoma.

UNNAMED MID-GEORGIA LOWER EOCENE ROCKS—In the west-central part of the Georgia coastal plain, lower Eocene rocks consist of medium-grained, calcareous, often dolomitic, glauconitic sandstone interbedded with soft, light-gray, calcareous, glauconitic clay. The sandstone ranges from unconsolidated to well indurated, depending on the amount of calcareous matrix that binds the sand grains. Although these strata are the probable equivalents of the combined Hatchetigbee Formation of eastern Alabama and southwestern Georgia, they are unnamed at present and are not shown on the correlation chart (pl. 2) because their relation to the Hatchibtigbee is still inexactly known.

These unnamed lower Eocene sand and clay beds become progressively more argillaceous and calcareous downdip to the southeast and grade into an off-white, micritic, glauconitic, argillaceous limestone that commonly contains the foraminifer *Pseudophragmina (Proporocyclina) cedarkeysensis* Cole, a species that is found in the Oldsmar Formation in Florida. This micritic limestone, unnamed at the time of this writing, grades seaward over a short distance into a typical Oldsmar lithology. Updip, the lower Eocene clay beds are lost, and the sands become progressively less marine until they grade into a predominantly fluvial thick sand sequence that may be part of the Huber Formation (Huddlestun, 1981).

In easternmost Georgia, lower Eocene rocks consist mostly of calcareous, glauconitic, argillaceous sand, cream to gray calcareous clay, and sandy, glauconitic limestone. Locally, some of the clayey beds are dark brown and silty and contain much fine-grained organic material. Northeastward, in South Carolina, lower Eocene strata consist of sandy, fossiliferous, glauconitic limestone that has recently been named the Fishburne Formation (Gohn and others, 1983).

DEPOSITIONAL ENVIRONMENTS—Most of the lower Eocene rocks in the study area were deposited in shallow open marine to marginal marine environments. The laminated silty sands of the Hatchetigbee Formation were deposited in a restricted marine area, probably on tidal flats. Periodically, slightly deeper marine waters covered the tidal flats, and the Bashi Formation was deposited during such a local short-lived transgression.

Seaward of this marginal marine area, the undifferentiated thick sequence of fine clastic rocks of early Eocene age was deposited in quiet, shallow to moderately deep, open marine waters in the area that is now western panhandle Florida. Open marine conditions characterized by slightly higher energy levels existed in the central part of the Georgia coastal plain during early Eocene time, and an interbedded sequence of marine sand and clays was deposited there. This sequence, unnamed at present, grades laterally to the northeast into shallow marine sandy limestone that represents the Fishburne Formation of South Carolina.

Both the shallow water, open marine, clastic lower Eocene strata of central Georgia and the deeper water, massive clay sequence of panhandle Florida grade into and interfinger with the Oldsmar Formation. The Oldsmar was deposited in warm, shallow, open marine water and represents a carbonate bank environment. The minor evaporites found occasionally in the lower part of the Oldsmar represent sabkha conditions that were short lived and not areally extensive.

ROCKS OF MIDDLE EOCENE AGE

Middle Eocene strata are present over almost all of the study area and can generally be divided into a downdip platform carbonate facies and an updip facies that is predominantly clastic. The carbonate facies of the middle Eocene extends much farther to the north and west than the carbonate rocks of the underlying early Eocene. Approximately half of the Georgia coastal plain, much of the eastern part of the Florida panhandle, and all of the Florida peninsula are underlain by middle Eocene carbonate rocks. In the remainder of the study area, the middle Eocene consists of marine to marginal marine clastic rocks.

The configuration of the top of the middle Eocene and the area where this unit crops out are shown on plate 6. Middle Eocene rocks in Alabama and southwestern Georgia are located farther gulfward than underlying rocks of early Eocene age. In contrast to this offlap relation, the lower Eocene is overlapped by middle Eocene strata in central Georgia and in South Carolina. The top of the middle Eocene is contoured to the point where the unit pinches out in its outcrop area but only to the limit of well control in eastern Georgia and South Carolina. In these areas, the middle Eocene is mostly overlapped by younger rocks.

The effect of several large-scale structural features is reflected on the middle Eocene surface. Although many of these features are recognizable on maps of the tops of older units (pls. 3, 4), their locations and shapes are different on the middle Eocene map (pl. 6). The Peninsular arch is poorly defined on plate 6, and its surface is highly irregular, probably as a result of erosion and dissolution of the top of the middle Eocene. The top of middle Eocene strata in this area is generally higher than 200 ft below sea level. The Southeast and Southwest Georgia embayments and the South Florida basin are present as low areas on the middle Eocene top, but they are not as pronounced as they are on the maps of older units. These basins were probably relatively quiescent and were being filled during middle Eocene time. The Gulf Coast geosyncline was actively subsiding during the middle Eocene, as the steep, steady gulfward slope of the top of the unit in western panhandle Florida shows. The configurations of the unnamed negative area in east-central Georgia and of the high area parallel to it in southeastern South Carolina are similar on the middle Eocene top to those on older units.

Several faults of small to intermediate throw first occurred during middle Eocene time (pl. 6). Unlike the large-displacement faults in southwestern Alabama that affect the entire column of rocks mapped for this study, most of the faults shown on plate 6 in central